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WERE SOLAR NEUTRONS OBSERVED BY NEUTRON MONITORS ON 1984 APRIL 25?

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ABSTRACT

The 3B/X13 solar flare beginning at 2356 UT on 1984 April 24 was identified as a solar neutron event by the γ -ray spectrometer on the *Solar Maximum Mission* spacecraft and by the observation of protons resulting from neutron decay by the University of Chicago experiment on board the *ISEE 3* spacecraft. Evidence for a possible ground-based response to the solar neutrons was not reported until recently. In this paper the neutron monitor data for locations within 50° of the subsolar point during the solar flare event are presented and analyzed. The difficulties in identifying this possible ground-based response are discussed in detail.

Subject headings: Sun: flares — Sun: particle emission

I. INTRODUCTION

The solar flare that began at 2356 UT on 1984 April 24 (at heliographic coordinates 11° S, 45° E) was one of the most copious X-ray and γ -ray emitters of the entire 21st solar cycle. The 1–8 Å soft X-ray peak emission of this optical class 3B flare was 1.3×10^{-4} W m $^{-2}$ (Boulder X-ray classification X13). This flare is the third solar flare neutron event as identified by spacecraft (Chupp 1990). Of the known solar neutron events, the event of 1984 April 24/25 also has the distinction of being the largest hard X-ray event (S. R. Kane 1985, private communication) and having the largest 2.2 MeV γ -ray fluence (Chupp 1990) as measured by the hard X-ray burst spectrometer (HXRBS) and the γ -ray spectrometer (GRS) experiments on the *Solar Maximum Mission* (SMM) spacecraft. Further identification of this flare as the source of neutrons has been made by Evenson, Kroeger, and Meyer (1985), who observed and identified prompt protons resulting from neutron decay with the University of Chicago experiment on board the *ISEE 3* spacecraft. The purpose of this paper is to report the results of a search for a response in ground-level neutron monitor data to the presence of solar neutrons at the top of the atmosphere.

II. POSSIBLE DETECTION SITES

The subsolar point on the surface of the Earth at the onset of the X- and γ -ray emission of this solar flare was $13^\circ 2$ N, 180° E. The location of all neutron monitors within 50° of the subsolar point is shown in Figure 1. Additional information about these stations is given in Table 1.

III. DATA

We have examined the neutron monitor data from all stations listed in Table 1. Whenever possible, we have tried to organize the data in equivalent time intervals for direct com-

parison. No short-time digital data are available from either the Mount Norikura, Japan, or the Brisbane, Australia, neutron monitors, which were configured to provide only hourly data. However, there was a supplemental analog output of the cosmic-ray intensity recorded at Brisbane, and we have attempted to reconstruct the 10 minute count rate of this monitor from this output. Unfortunately, the manual scanning of the recording chart results in short-time data of reduced accuracy.

The 10 minute relative count rates of the three Japanese low-altitude neutron monitors are shown in Figure 2. The respective average count rates between 2200 UT on April 24 and 0300 UT on 1984 April 25 were used as the reference levels in evaluating these data. No statistically significant "signal" is recognizable in the data recorded between 0000 and 0010 UT at Fukushima and Tokyo-Itabashi or from the chart readings of the Brisbane monitor (data not shown). In the time interval 0000–0010 UT we find a $1.7 \pm 0.5\%$ increase in the data from the Morioka monitor.

A standard small-signal recovery technique was applied on the assumption that a solar neutron event would impose a small increase on the cosmic-ray background. We have combined the data for all three Japanese low-altitude neutron monitors (weighted by the average count rate of each monitor) to recover any possible "signal" that could be associated with the solar neutron event. The result of this combination (Fig. 3) shows a distinct increase in the count rate during the interval 0000–0010 UT in time coincidence with the observation of solar neutrons by the SMM GRS (Chupp 1990).

IV. DISCUSSION

The time history of the different emissions during the 1984 April 24/25 solar flare event have been reviewed by several authors (e.g., Nakajima *et al.* 1988; Chupp 1990). A compre-

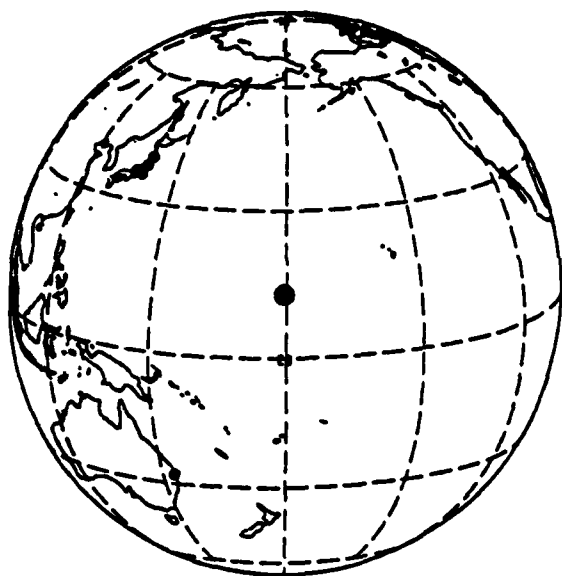


FIG. 1.—Map of possible neutron monitor detection sites for the 1984 April 24/25 solar neutron event. The map is oriented on the subsolar point (large solid circle).

hensive compilation of solar-terrestrial data for this event was published by Coffey and Allen (1987). The $H\alpha$ onset was observed around 2356 UT on April 24. X- and γ -ray emission started at 2359:40 UT and reached a maximum around 0000:30 UT on April 25. A type II radio burst with onset at 2359:53 UT was observed until 0001 UT, when it became obscured by the powerful type IV radio emission. Evidence for the presence of solar neutrons near the Earth could be found in the SMM GRS data after 0004 UT, and the first neutron decay protons in the energy range 25.7–47.5 MeV were observed by the University of Chicago experiment on board the *ISEE 3* spacecraft around 0020 UT (Evenson, Kroeger, and Meyer 1985). The coincidence of the small increases in the count rates of the Tokyo-Itabashi and Morioka neutron monitors between 0000 and 0010 UT on 1984 April 25 is suggestive of a small contribution to the total count rate of these neutron monitors by an additional short-duration burst of solar neutrons. Furthermore, the time coincidence of the small pulses between 0000 and 0010 UT and the expected arrival time of high-energy (>400 MeV) neutrons released at

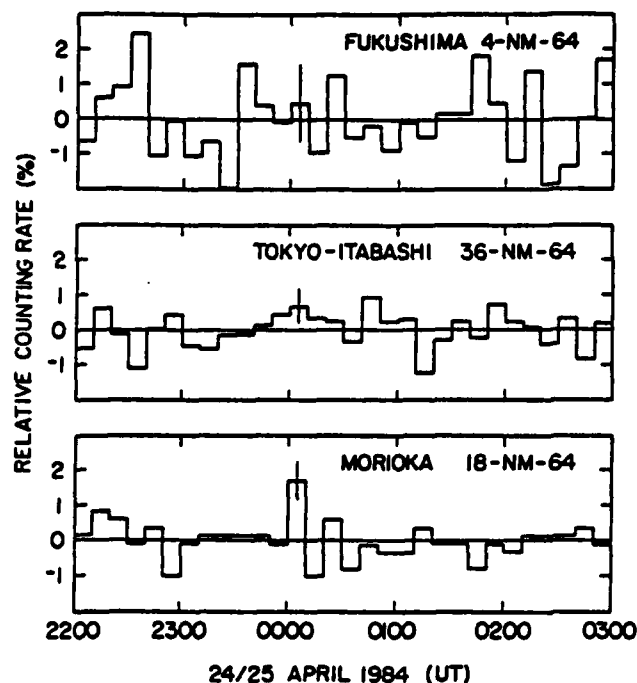


FIG. 2.—Relative 10 minute count rates of the Tokyo-Itabashi, Morioka, and Fukushima neutron monitors.

the Sun at the same time as the high-energy γ -rays suggests an incident pulse of solar neutrons at the top of the atmosphere. The decay protons observed by Evenson *et al.* were in the energy range between 25.7 and 47.5 MeV. Neutrons (or protons) in this energy range have a mean velocity of $0.27c$. Assuming that the neutrons that produced the decay protons observed by Evenson *et al.* left the Sun at the same time as neutrons of higher energy, the observation of the small increase in the count rate of the ground-level neutron monitors in the time interval 0000–0010 UT is consistent with the presence of solar neutrons having energies >400 MeV.

An inspection of the neutron monitor data for 1984 April 24/25 shows that this was not a "quiescent" period, as there are persistent variations exceeding the 1σ level in the short-time cosmic-ray data obtained from the worldwide neutron monitor network. The cause of these variations masking a possible solar neutron event may be a turbulent interplane-

TABLE 1
STATIONS LOCATED WITHIN 50° OF THE SUBSOLAR POINT FOR THE 1984 APRIL 24/25 SOLAR NEUTRON EVENT

NAME	GEOGRAPHIC COORDINATES		TYPE OF NEUTRON MONITOR	CUTOFF RIGIDITY (GV)	METERS ABOVE SEA LEVEL	ANGLE FROM SUBSOLAR POINT	NOMINAL AIR MASS ALONG LINE OF SIGHT ($g\ cm^{-2}$)
	Latitude	Longitude					
Tokyo-Itabashi	35.75	139.72	36-NM-64	11.61	20	42.2	1390
Fukushima	37.75	140.48	4-NM-64	10.59	66	42.5	1397
Morioka	39.70	141.13	18-NM-64	10.23	131	42.9	1406
Mount Norikura	36.12	137.56	4-NM-64	11.44	2770	44.0	1031
Brisbane	-27.50	153.01	9-NM-64	7.02	2	48.1	1542

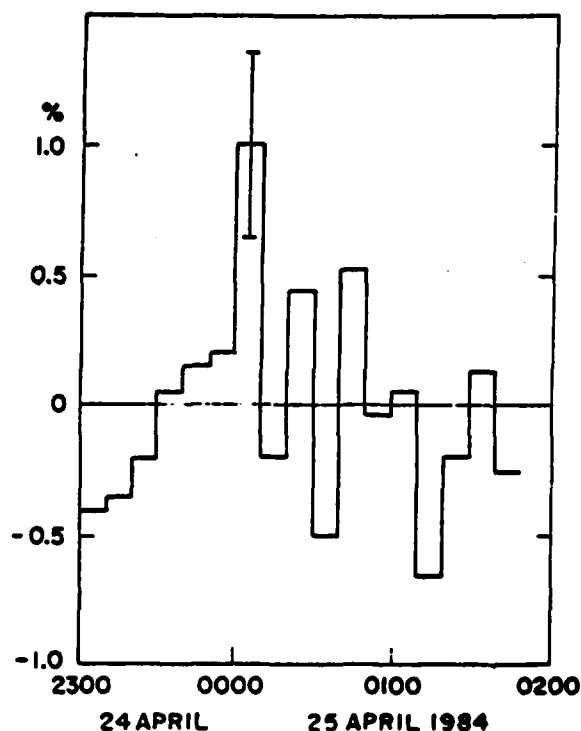


FIG. 3.—Normalized composite increase showing the probable solar neutron "signal" in the 10 minute data from the Tokyo-Itabashi, Morioka, and Fukushima neutron monitors.

tary magnetic field, which, in turn, is reflected in disturbed geomagnetic conditions. Unfortunately, there is very little interplanetary magnetic field data from the *IMP 8* spacecraft during this time (and no data at the time of this neutron event). However, the fragmentary data available at 10 UT on April 25 (Couzen and King 1986) indicate "nonquiescent" conditions.

The geomagnetic records during the 1984 April 24/25 time period indicate the potential for a developing magnetic disturbance. Geomagnetic field variations indicative of a solar flare effect (SFE) starting around 2359 UT on April 24 were recorded by several magnetometer stations. This effect was initially reported as a sudden commencement (SC) in *Solar-Geophysical Data* (1984). The character of this SFE can be deduced from the magnetic records at locations in the Pacific Ocean area; at Honolulu the *H*-component increased by

approximately 50 nT for about 20 minutes (Allen *et al.* 1987), whereas at Kakioka there was a sudden decrease in *H* with a maximum amplitude of -32 nT at 0001 UT followed by a depression of about -15 nT for the next 30 minutes (Harada, Kuwashima, and Uwai 1987). The character of these magnetic field variations suggests that they were of ionospheric rather than magnetospheric origin. There was no enhanced magnetic activity around 00 UT either at San Juan or along the Alaska magnetometer chain (Allen *et al.* 1987). Therefore, an effect on cosmic-ray cutoff rigidities is very unlikely, although a possible increase in the count rate of the Japanese neutron monitors of the order of 0.1% due to geomagnetic effects cannot totally be excluded.

V. COMPARISON WITH THE 1982 JUNE 3 GROUND-LEVEL SOLAR NEUTRON EVENT

It is useful to compare this possible ground-level detection of solar neutrons with the event of 1982 June 3 when an increase attributed to solar neutrons was recorded by several European neutron monitors. Table 2 gives the relative increases and the air mass along the line of sight for the solar neutron event observed by ground-level neutron monitors on 1982 June 3 (Debrunner *et al.* 1983; Chupp *et al.* 1983, 1987). The "signal" is not uniquely recognizable in the Kiel data, since it is masked by statistical fluctuations. These increases are displayed in Figure 4 along with our suggested signal for the 1984 April 24/25 solar neutron event. For this comparison all increases are expressed relative to the average count rate of a neutron monitor with cutoff rigidity 4.6 GV. If our identification is correct, then the 1984 April solar neutron event is similar in magnitude to the 1982 June 3 event. The same conclusion was obtained by Evenson (1988) when he compared his identification of the decay protons from this 1984 April event with the decay protons from the 1982 June solar neutron event (Evenson, Meyer, and Pyle 1983).

VI. CONCLUSIONS

Several factors combined to make the solar neutron event on 1984 April 24/25 difficult to observe with ground-level neutron monitors. The time of day and time of year of the event caused the subsolar point to be distant (more than 42°) from any operating monitor (compared with 23° at the time of the 1982 June 3 event). The consequent large air mass traversed reduced any original signal significantly. Furthermore, the event occurred during a geomagnetically disturbed

TABLE 2
NEUTRON MONITOR RECORDINGS OF THE 1982 JUNE 3 SOLAR NEUTRON EVENT^a

NAME	GEOGRAPHIC COORDINATES		TYPE OF NEUTRON MONITOR	CUTOFF RIGIDITY (GV)	METERS ABOVE SEA LEVEL	ANGLE FROM SUBSOLAR POINT	AIR MASS ALONG LINE OF SIGHT (g cm^{-2})	PERCENT INCREASE (5 minute data)
	Latitude	Longitude						
Jungfraujoch	46°55	7°98	IGY	4.63	3554	25°	742	4.2
Lomnický štít	49.20	20.22	8-NM-64	4.00	2632	25	881	2.8
Rome	41.90	12.52	12-NM-64	6.31	60	23	1105	2.0
Kiel	54.33	10.13	18-NM-64	2.33	54	33	1222	0.6

^a Chupp *et al.* 1987.

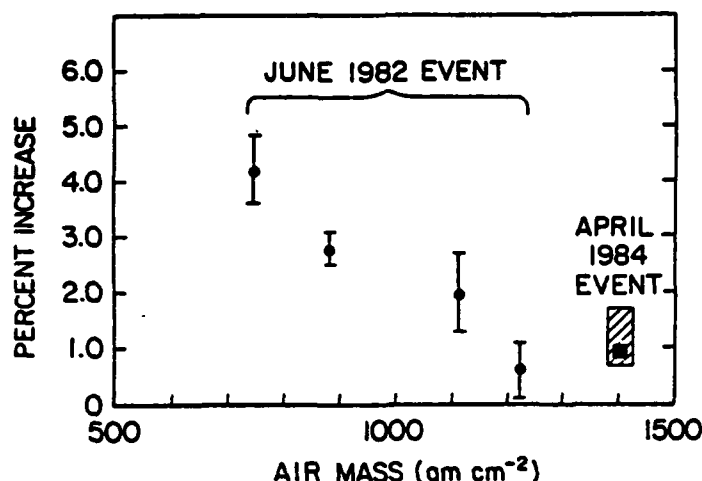


FIG. 4.—Percentage increase recorded by the neutron monitors observing solar neutron events. The 1982 June event (5 minute data) is at the left in this figure, while the "square" to the right is our estimate of the percentage increase from the 10 minute data available for the 1984 April event. (For details see text.)

period, making precise signal identification more difficult. In addition, two of the monitors involved were not specifically configured for short-term recordings. Mount Norikura had hourly recordings only, and Brisbane had, in addition to its hourly recordings, only a strip chart "event" recorder designed for backup use.

On the basis of our analysis we conclude that without additional evidence it is not possible to make a final statement as to whether or not solar neutrons were indeed observed by neutron monitors on 1984 April 25. If we assume a response to be present, this would then imply that the number of solar neutrons with energy > 400 MeV present near the Earth in the 1984 April 24/25 event was approximately the same as in the 1982 June 3 event. This is in agreement with similar

conclusions for lower energies obtained from the analysis of the *ISEE 3* neutron decay proton data (Evenson 1988) and of the *SMM* GRS response (D. J. Forrest 1988, private communication).

By determining the sensitivity of neutron monitors to solar neutrons (Debrunner, Flückiger, and Stein 1988, 1989) and assuming that this solar neutron event had an injection profile and energy spectrum similar to those of the 1982 June 3 event, it is possible to estimate a theoretical response for the three Japanese low-altitude neutron monitors. In this case the detectability of this event is slightly increased, since the cosmic-ray-induced background count rate of the Japanese neutron monitors is lower than the background count rate of the European mid-latitude stations. This is because of the higher cutoff rigidity of approximately 11 GV at the Japanese stations. The results indicate that under the specified assumptions a "signal" of the order of 0.5% would be possible. Thus the observed increase seen at the Japanese stations in the time interval 0000–0010 UT on 1984 April 25 may have resulted, at least in part, from an influx of high-energy solar neutrons at that time.

The problems encountered in identifying a unique neutron monitor response for a "known" solar neutron event illustrate the difficulty in searching for neutron events using historic neutron monitor data. This event was included in a search for possible solar neutron events by Takahashi *et al.* (1986) but was not identified as a specific event, perhaps because of the large variations present in the cosmic-tray data; consequently, the "signal" did not pass their statistical test.

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